Maximum Power Point Tracking for PV Systems

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Introduction

Solar panels have become less expensive and more efficient in recent years, making them more accessible to many different applications. These improvements have resulted from research into the materials that compose photovoltaic (PV) cells, as well as the design of hardware and methods to draw the most power possible from a given solar array. The maximum power output of a solar cell is achieved at a voltage that varies with changing ambient conditions, such as temperature and solar irradiance. This means that if a PV system is set up to run at a constant voltage, it will almost never be operating at the optimum voltage [1]. The development of Maximum Power Point Tracking (MPPT) has solved this problem. MPPT is the process of finding the optimum voltage and switching the system's operating voltage to run at this level. The following sections will discuss the cause of variations in solar cell performance and implementation of MPPT technologies.

Effect of Temperature and Irradiance on Solar Cells

A solar cell is made up of a P-type semiconductor and an N-type semiconductor combined to form a P-N junction. The most commonly used material is silicon, because it is relatively inexpensive, and because silicon engineering is well understood from being used in many other applications [2]. A solar cell can be modeled using the equivalent circuit shown in Figure 1:

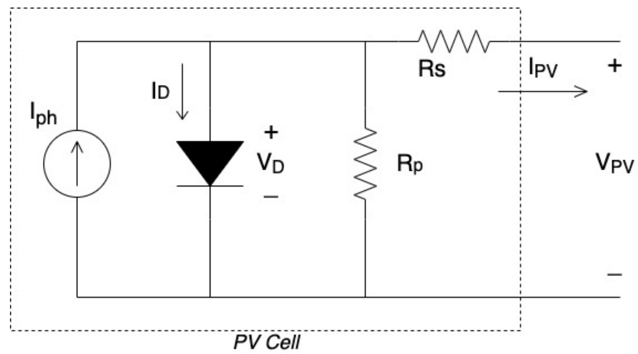


Figure 1: Equivalent Circuit of a Solar Cell (Figure by Emily Calandrella)

The theoretical maximum power output of a solar cell is the product of its open circuit voltage (V_{oc}) and short circuit current (I_{sc}):

$$P_{OUT} = V_{OC} * I_{SC} \quad (1)$$

V_{oc} and I_{sc} are the output voltage and current when the PV array is not connected to a load. These values are not constant after the solar cell is manufactured; they are affected by ambient conditions.

Temperature

The open circuit voltage of a solar cell is determined by the band gap of the semiconductor that the cell is made out of. The band gap represents the amount of energy required to excite an electron to a state where it can move across the semiconductor. A lower band gap in a solar cell means that electrons excited by energy from the sun will be released at a lower energy state, which corresponds to a lower V_{oc} [3].

Research has shown that as the temperature of a PV cell increases, the band gap decreases [4]. As shown in Equation 1, this causes the maximum power output to decrease.

Irradiance

Solar irradiance, which is the rate at which energy from the sun reaches the solar cell, has the opposite effect on the open circuit voltage; V_{oc} increases as irradiance increases. I_{sc} also increases with increasing irradiance. From Equation (1), this causes the theoretical output power of the PV array to increase [4].

Maximum Power Point Tracking

Why is MPPT needed?

The ambient temperature and irradiance are never constant as a solar array sits outside generating power, so the system's open circuit voltage and short circuit current are always fluctuating. This means that the theoretical maximum power output is constantly changing. Figure 2 shows I-V and P-V curves for an example solar array.

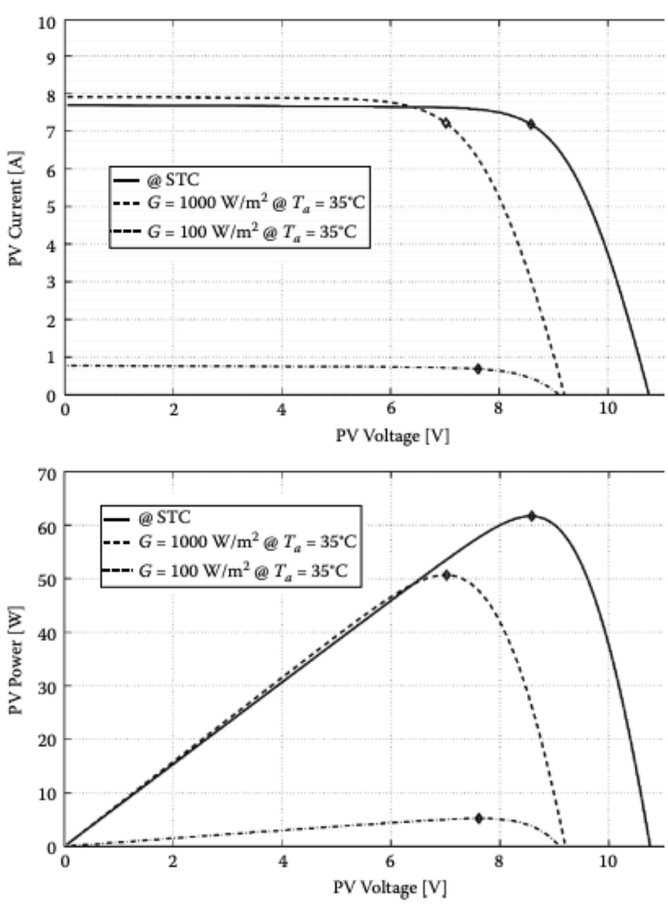


Figure 2: I-V and P-V Curves [5]

In Figure 2, each plot gives curves for three different temperature and irradiance conditions. STC, or Standard Testing Conditions, indicates a cell temperature of 25˚C and irradiance level of 1000W/m^2. The curve for each set of ambient conditions has a point marked where the power is at its peak. The voltage at this point is called the Maximum Power Point (MPP). MPPT techniques find this voltage and set the operating voltage to match it in order to ensure that the PV array is outputting as much power as possible at any given moment.

How is MPPT implemented?

While MPPT can be implemented solely using hardware, it is most commonly implemented through software algorithms or a combination or both [5]. Two main groups of methods exist for implementing MPPT: indirect and direct.

Indirect Methods

Indirect methods use models of a PV array that are generated ahead of time to decide what the MPP should be and set the operating voltage accordingly [5]. This means the actual output power is never measured, so the resulting MPP is an approximation. Additionally, if ambient conditions vary too much from the model, significant energy losses can occur.

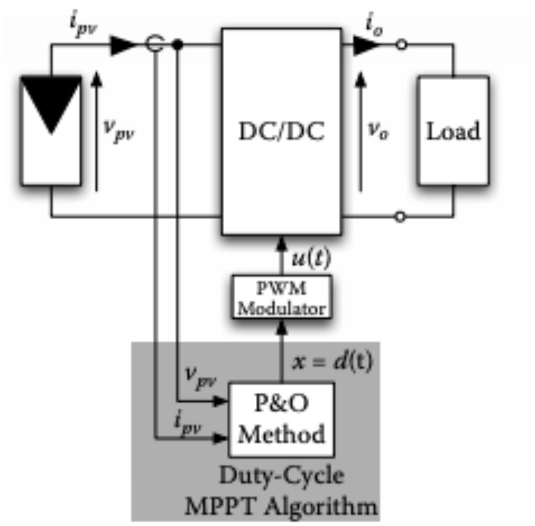
One example of a simple indirect method is based off of experimental research showing that the MPP is usually close to 76% of the open circuit voltage. A switch in series with the PV module can be used to periodically disconnect the module and measure V_{oc}, and then the system voltage is set to 0.76*V_{oc} [5]. This method is simple but not always accurate, and of course when the array is disconnected in order to make measurements, it is not providing any power.

Direct Methods

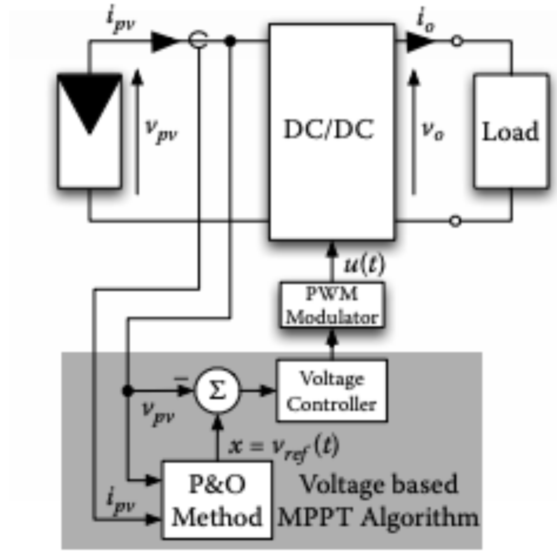
Direct methods, on the other hand, are more complicated but far more accurate. Usually, the PV output current and voltage are both measured periodically, and adjustments are made for varying operating conditions. The most popular direct method is called Perturb and Observe (P&O). To implement P&O, the first step is to measure the module's output power. Then the system voltage is changed using a DC/DC converter, and the resulting power is measured. If the power increased after the change, then the voltage level is getting closer to the MPP, so the process is repeated. If the power output decreased after the voltage change, then it passed by the MPP, so the voltage level is changed back in the opposite direction. This method is independent of the characteristics of the specific solar module, which makes it reliable and widely applicable [5].

Integration of MPPT into PV Systems

To add MPPT to a system, a DC/DC converter is placed between the PV array and the load. The converter is used to adjust the system's operating voltage. Figure 3 shows two examples of how to change the operating voltage when using the P&O method. One way is to change the duty cycle of the converter (3a). The second way is to control the converter using an error amplifier that compares the operating voltage with a reference voltage, and adjust the reference voltage as the MPP changes (3b).



3a



3b

Figure 3: Implementation of P&O Algorithm [5]

There are a few ways to integrate the DC/DC converter into the PV system. For small-scale, off-grid applications, solar panels are often set up to charge a battery, which then sends power to a load. A charge controller is required between the PV array and the battery to make sure the battery is not overcharged or over discharged. MPPT is commonly integrated into these charge controllers [1]. Another option is to attach an optimizer to each separate solar panel. The advantage of this method is that it takes into account differing ambient conditions across a solar array. For example, if some of the PV modules in a system were in the shade and some were not, the optimizers would set each panel to run at its own MPP. For large-scale applications, the MPPT is sometimes done within the inverter that changes the DC output of the solar array into an AC current for distribution [6].

Conclusion

Maximum Power Point Tracking is an essential component of a PV system. The development of algorithms to optimize MPPT methods will continue to advance solar as a viable energy source. Other improvements in this field are being made as well. Multi-junction cells, for example, achieve a higher efficiency by allowing more of the solar spectrum to be converted into energy. They are currently far more expensive than silicon-based cells, but researchers are developing cheaper ways to manufacture them [7]. All of these advancements are important as we work to transition our world's energy systems from inexpensive fossil fuels to sustainable energy sources.

References

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